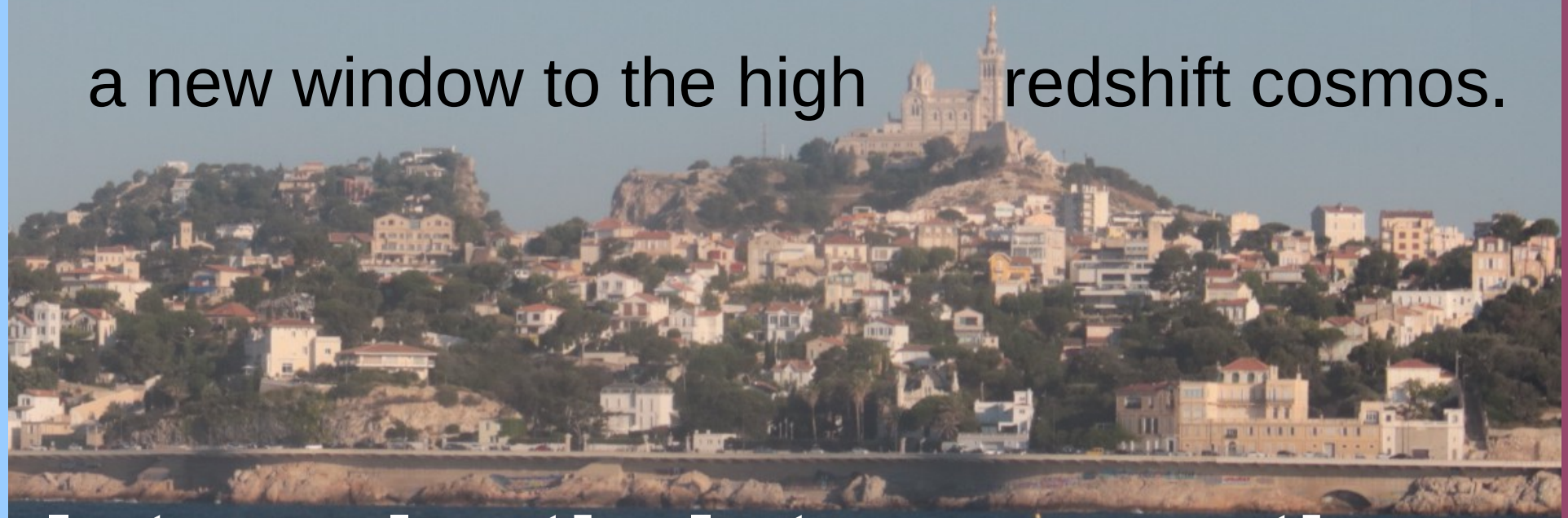
Classifying Damped Lyman Alpha Systems (DLAs) with their metal lines,

a new window to the high redshift cosmos.



Intergalactic Interconnections

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Ignasi Perez Rafols
Jordi Miralda Escudé
Pasquier Noterdaeme

Special thanks to George Becker

IEEC

ICCUB

Marseille
2018-07


Ly ?
Ly forest ?
DLA?

Observations

Deep/ wide Surveys

Intensity mapping

Absorption

Emission

Proximity tracers

Sunyaev–Zel'dovich effect

Tools

Correlation/Cross correlation

Stacking

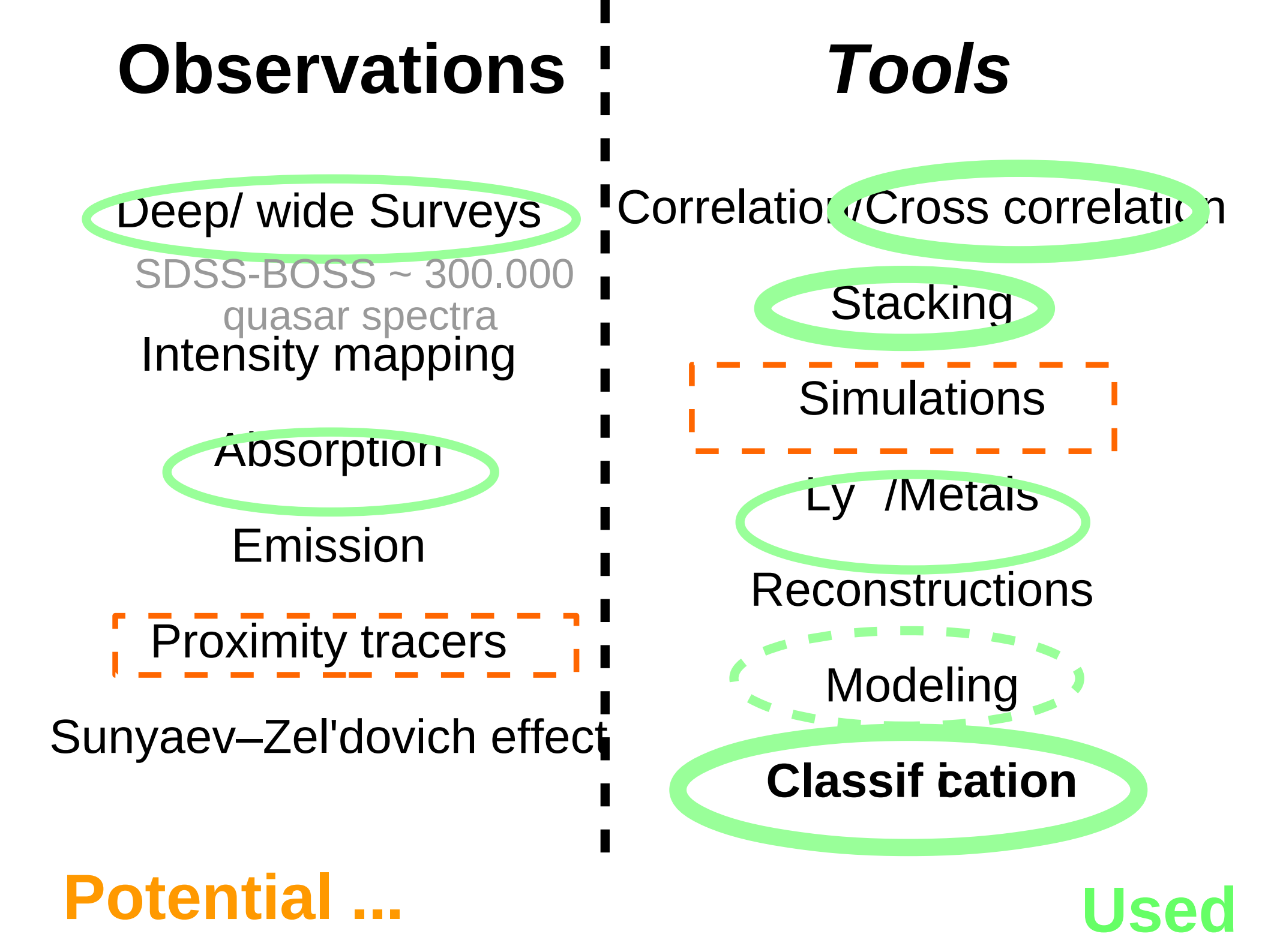
Simulations

Ly /Metals

Reconstructions

Modeling

Classif cation


Observations
Tools
Deep/ wide Surveys
SDSS-BOSS ~ 300.000 quasar spectra
Intensity mapping
Absorption
Emission
Proximity tracers
Sunyaev–Zel'dovich effect
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Classif cation
Potential ...
Used

Observations

Deep/ wide Surveys

SDSS-BOSS ~ 300.000 quasar spectra

Intensity mapping

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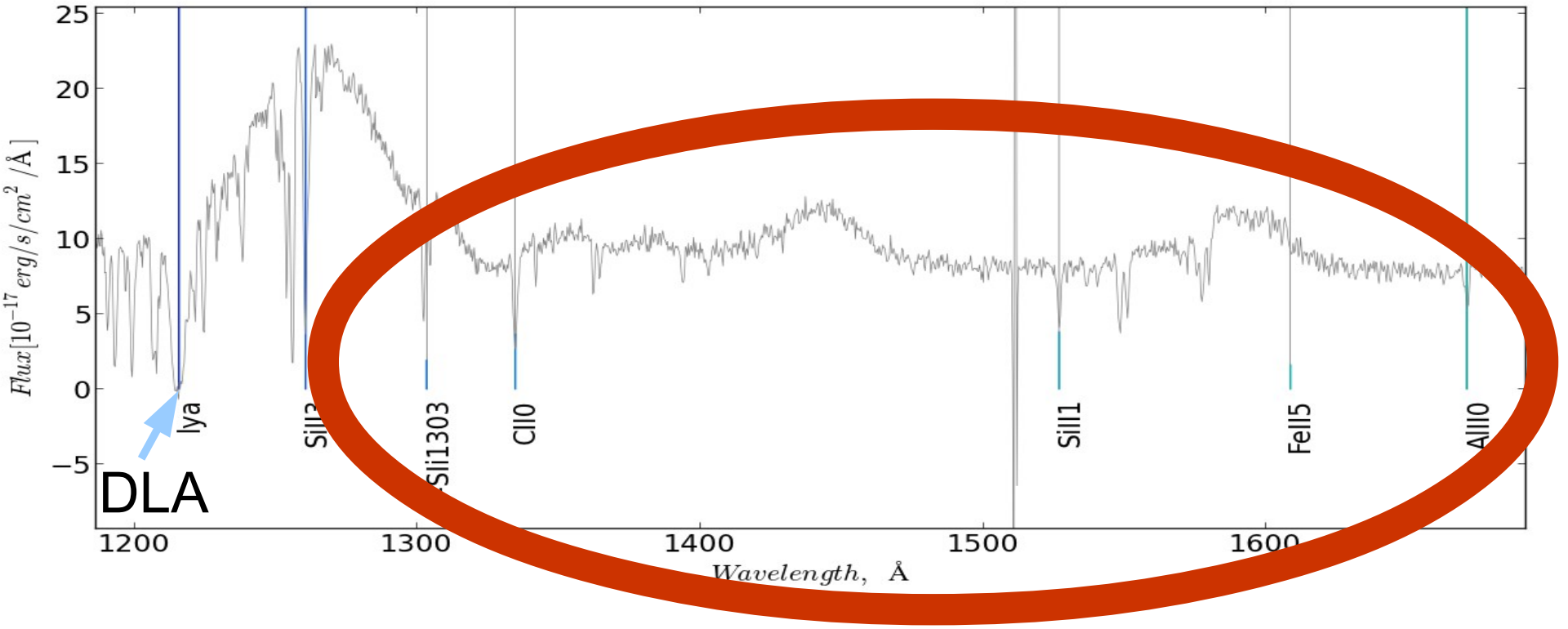
DLAs in BOSS spectra, we measure **metal line strength** for low ionization metals. We can **cross-correlate** with Ly forest and **stack** on metal strength

*



BOSS 55477-4216-0166
Redshift 2.6917

*Extremely good and exceptional Signal to noise!!!
DO NOT expect the rest to be as good as this...

DLAs ~ 30.000 in BOSS DR12 spectra, with measured **column density** and **redshift**, for which we can measure metal line strength and cross-correlation with Ly forest

*

DLA *candidates* Catalogue

DLA?

Not so Fast!

Pasquier's Noterdaeme +2012
Catalogue BOSS DR12

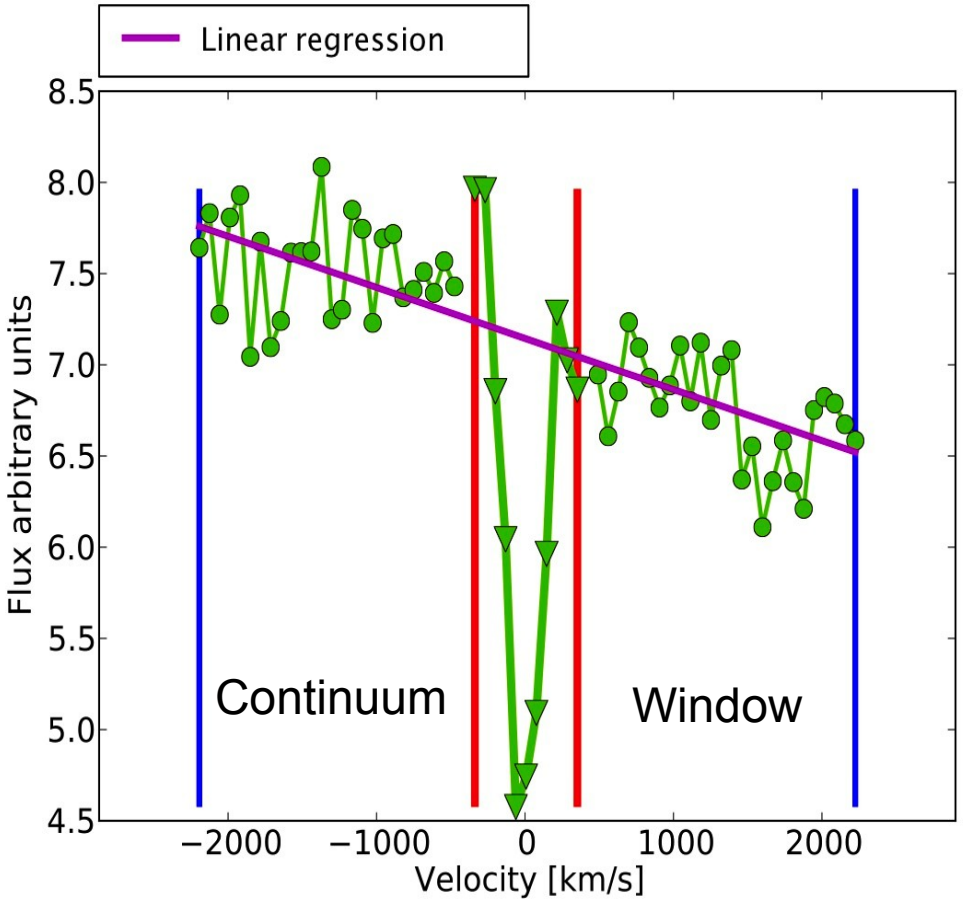
Other DLA catalogues

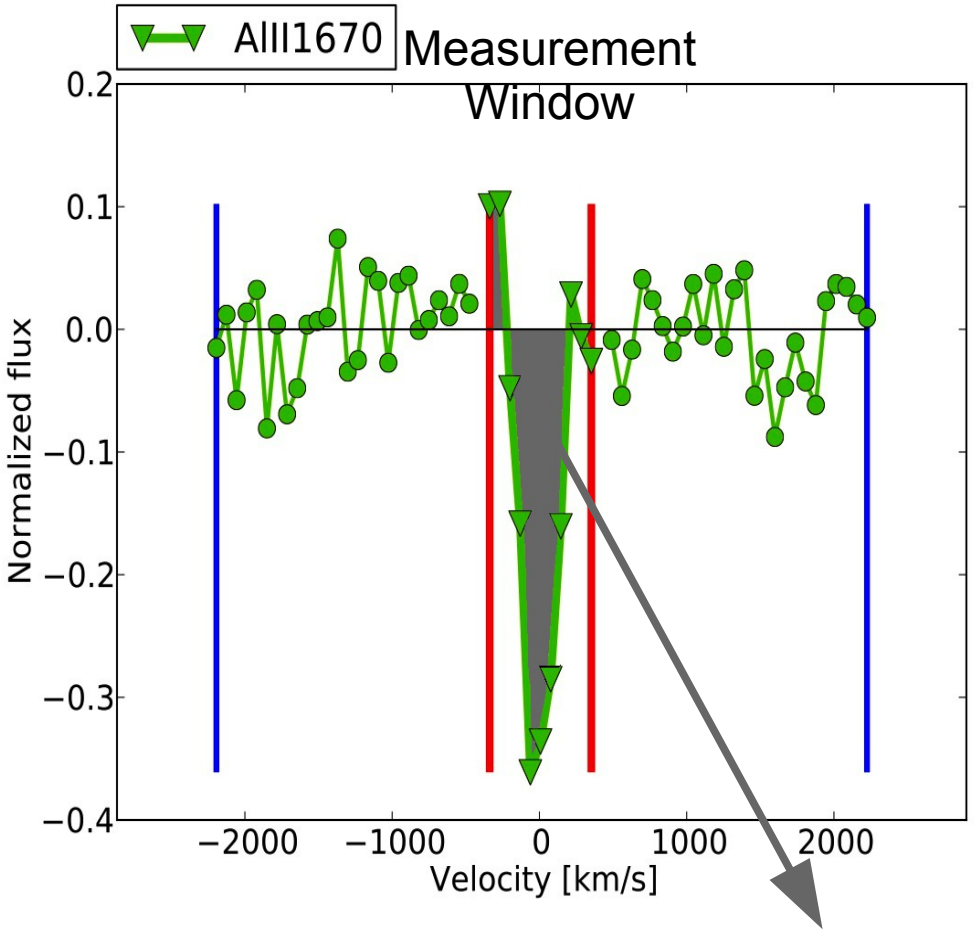
Park, D et al 2017, Gârnet, I. A. Et al 2017

*Average continum to noise BOSS Spectre is about 2.5

How to measure equivalent width in a noisy spectra?

Equivalent width mixture of metallycity and velocity dispersion





$$W = \sum_i F_i$$

$$\sigma_w = \sum_i n_{F_i}$$

Measured Equivalent width

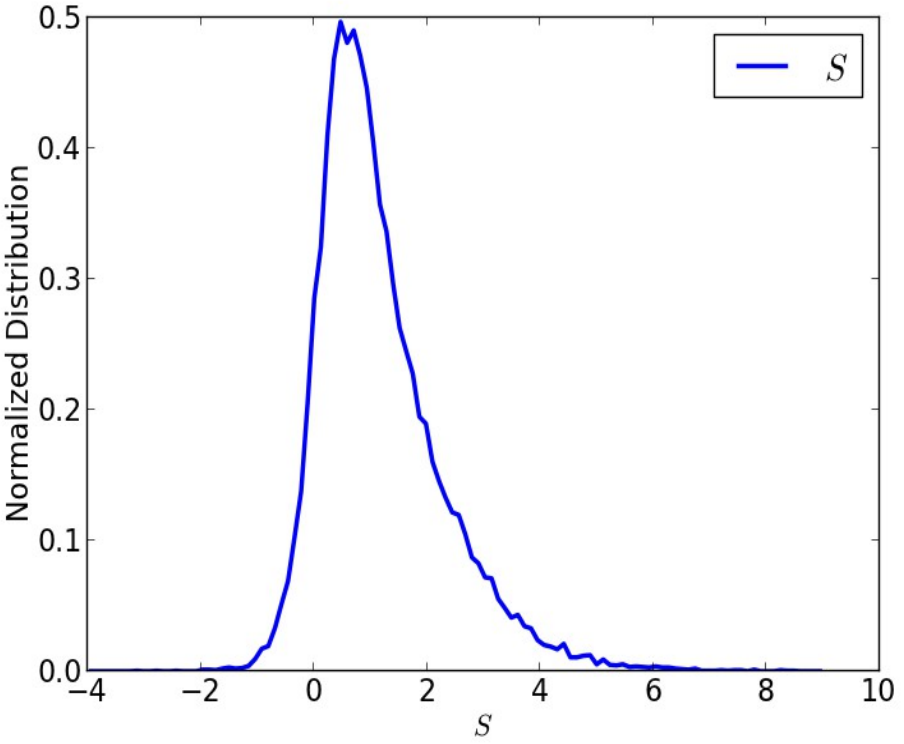
Andreu Arinyo-i-Prats

Metal Strength, this is NOT metallicity

- Metal strength parameter is defined as an optimal combination of the equivalent widths of 17 low ionization metal lines
-

$$S = \frac{\sum_i (\bar{W}_i / \sigma_i)^2 \cdot (W_i / \bar{W}_i)^2}{\sum_i (\bar{W}_i / \sigma_i)^2}$$

$$\sigma_S = \left[\sum_i \left(\frac{\bar{W}_i}{\sigma_i} \right) \right]^{1/2}$$

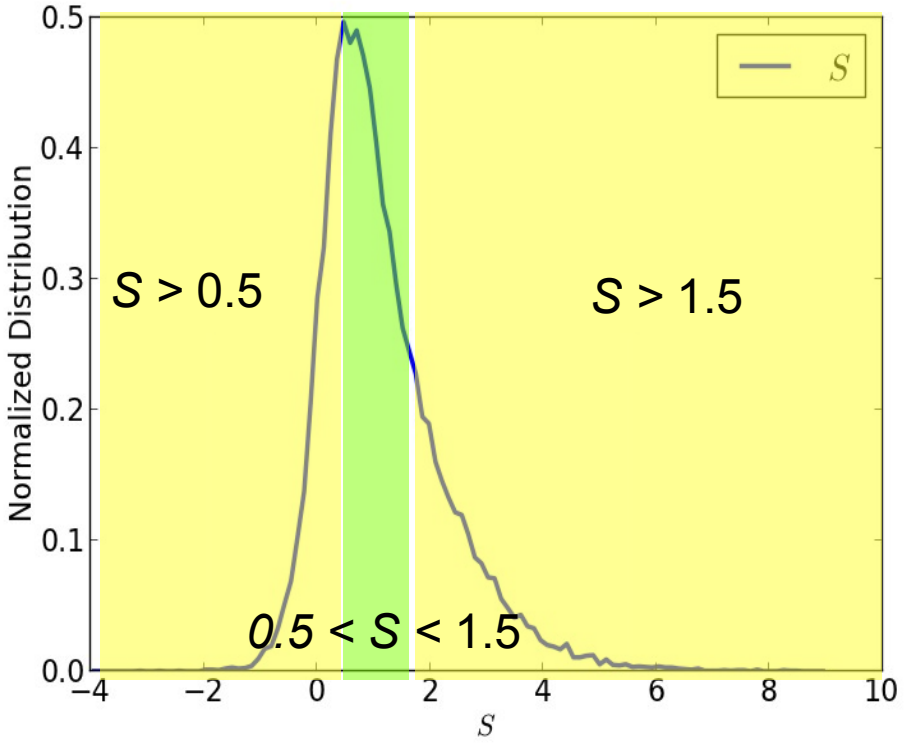


Arinyo-i-Prats 2018, arXiv:1805.00943

Metal Strength, this is NOT metallicity

- Metal strength parameter is defined as an optimal combination of the equivalent widths of 17 low ionization metal lines

- *S* is a noisy measurement
- *S* is build so he expected mean value is ~ 1
- We select *S* with noise < 0.5 to avoid mixing (23.000 DLAs)



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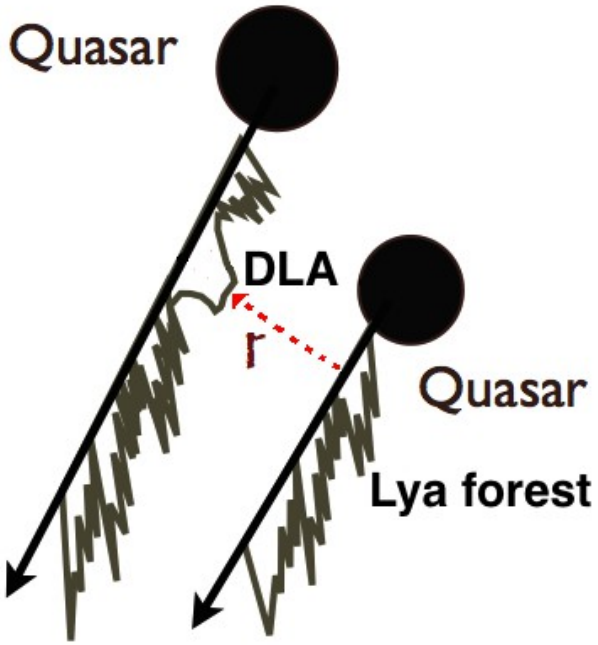
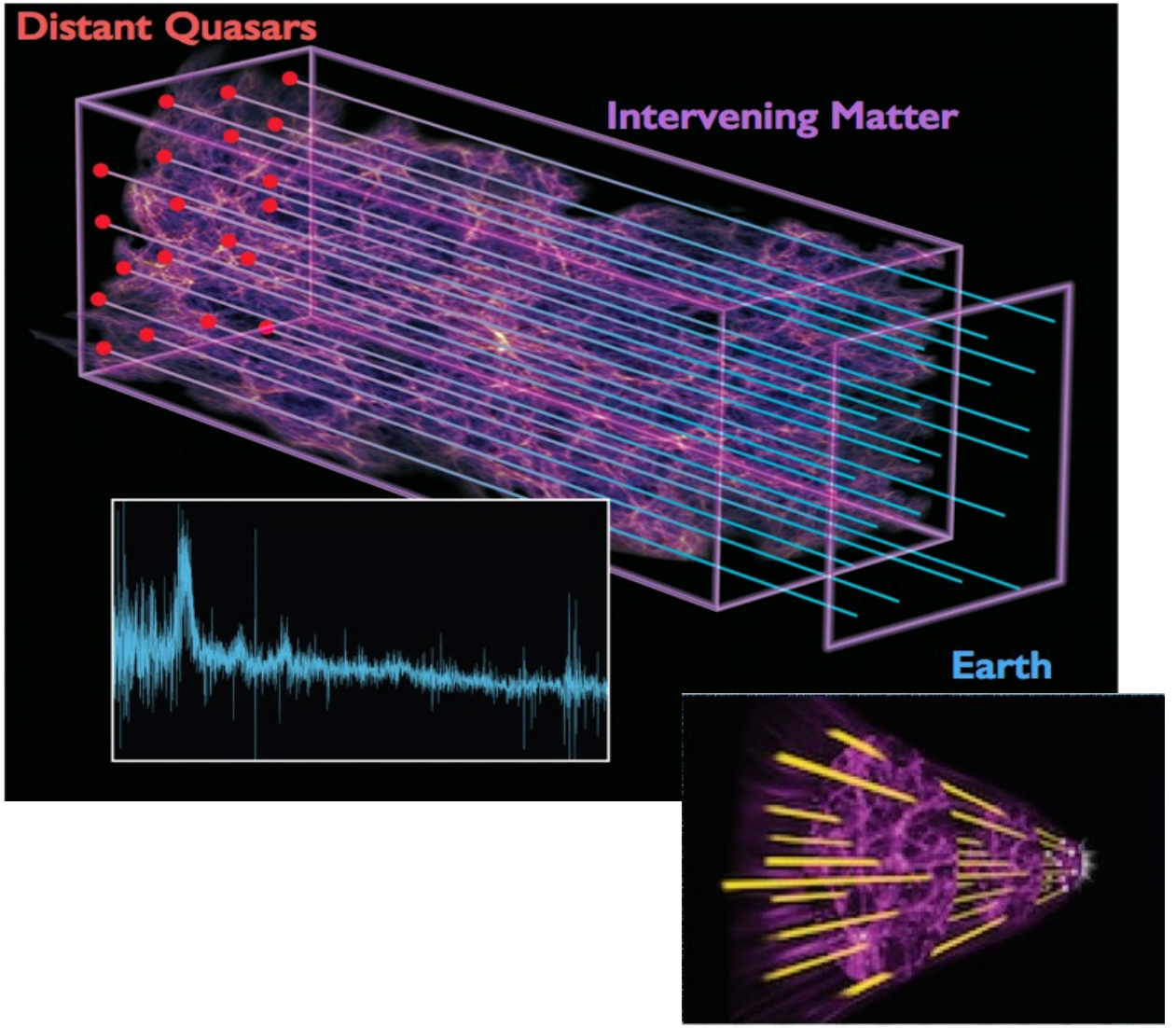
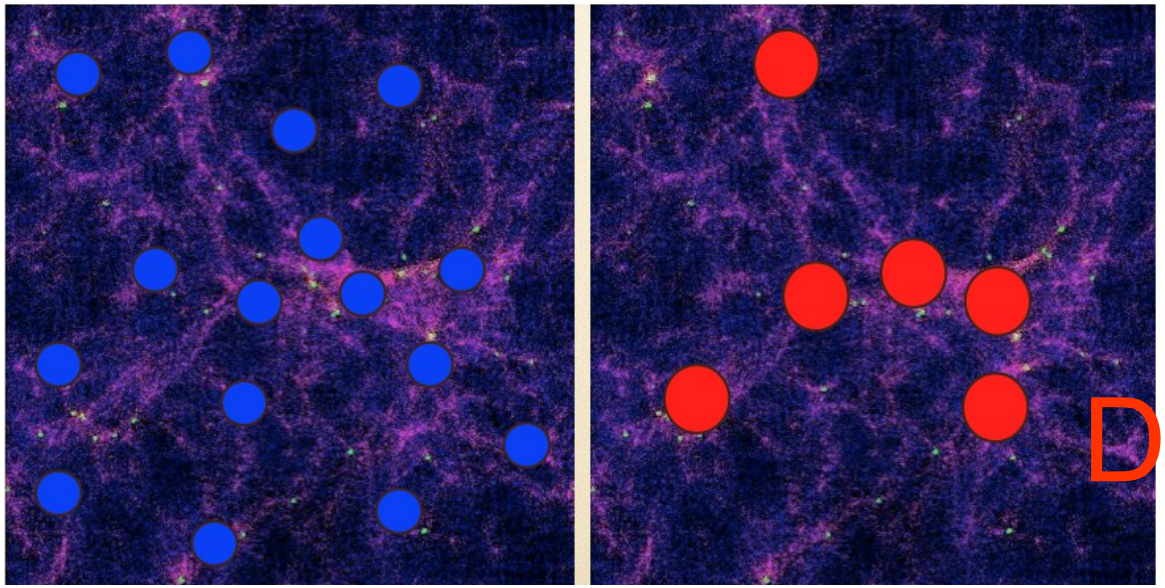
Cross-correlations
DLAs to Ly forest on BOSS





Uses of the DLAs classification, measuring DLA bias through cross-correlation with Ly forest

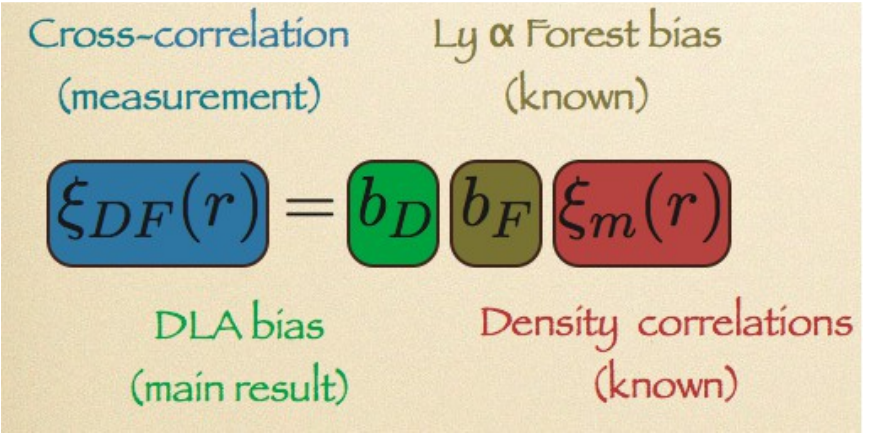


Lots of small DLAs? or Few big cross section DLAs?

DLA impact parameter?
Direct observations or bias

Cross- Correlations, bias factor for different kinds of tracers

For linear scales



- ...
- Quasars
- Lyman Alpha Forest
- DLAs

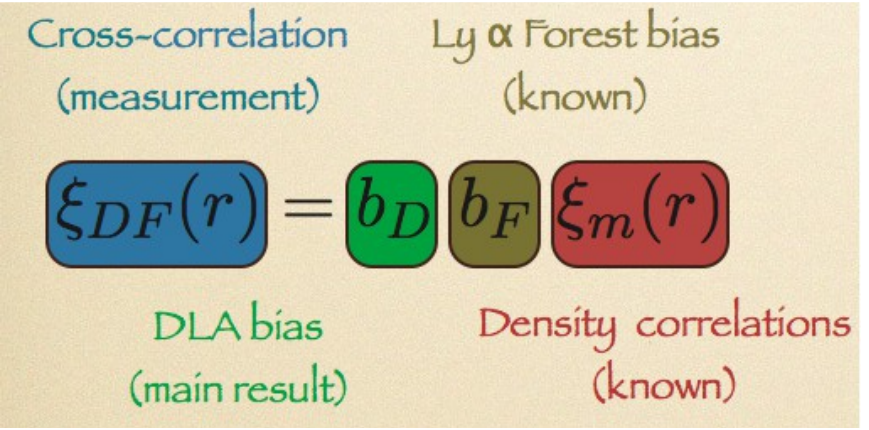
Corss-Correlation Font-Rivera et al. '14

Auto-Correlation Delubac et al. '14

Corss-Correlation Font-Rivera et al. '12
Perez-Rafols et al. '18

Cross- Correlations, bias factor for different kinds of tracers

For linear scales

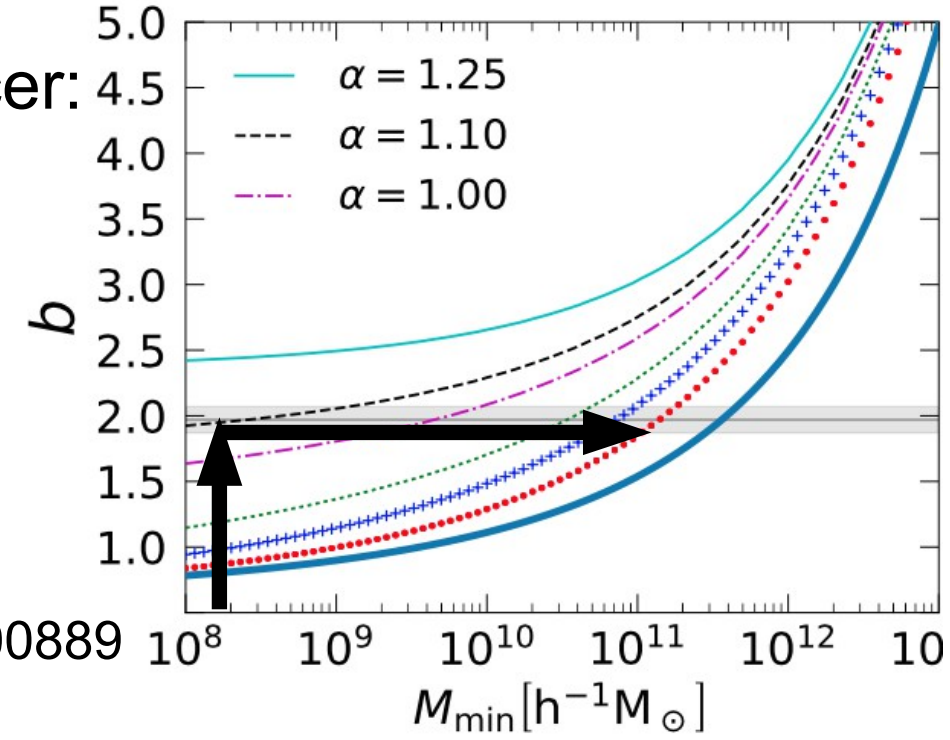


Correlations with any kind of tracer:

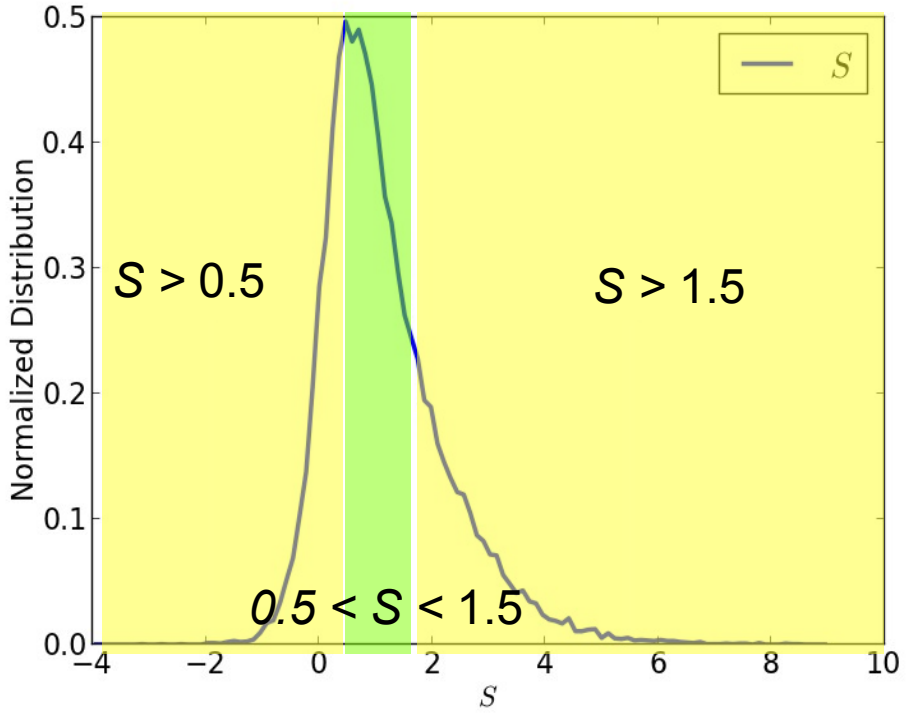
- ...
- Quasars
- Lyman Alpha Forest
- DLAs

Font-Ribera 2012

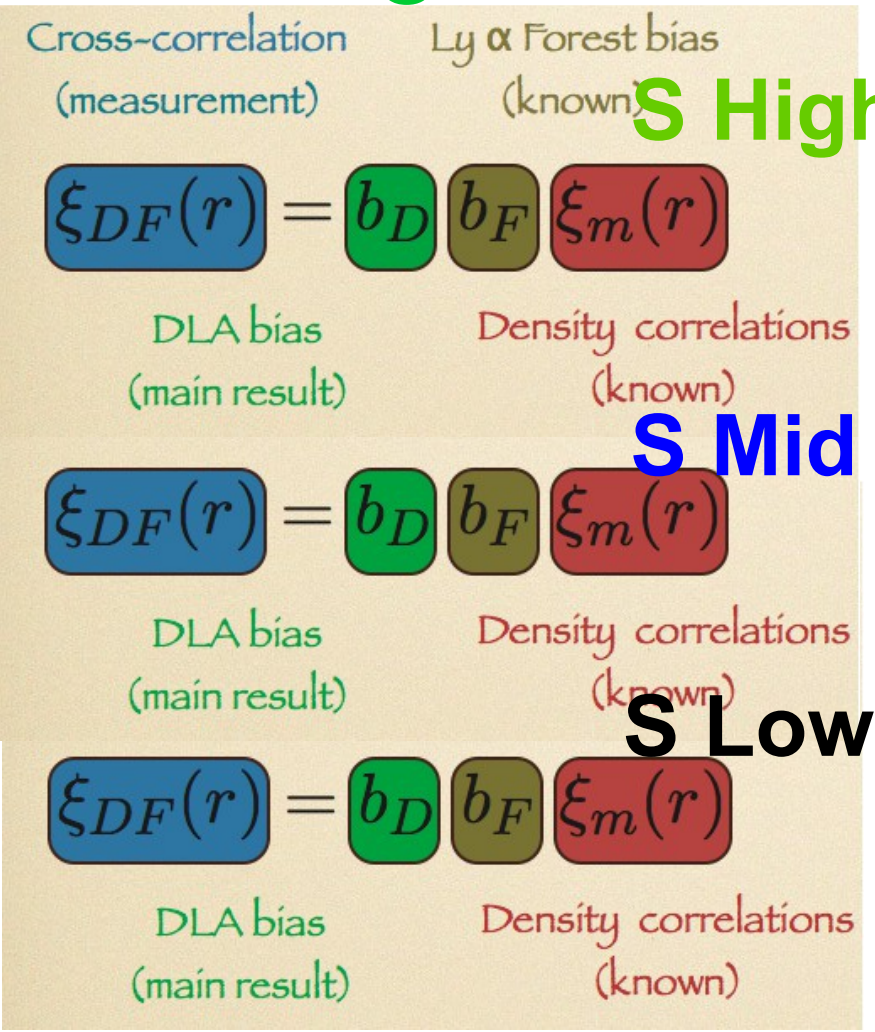
Perez-Rafols 2018a arXiv1709.00889



We trace different kinds of DLAs with their Metal Strength



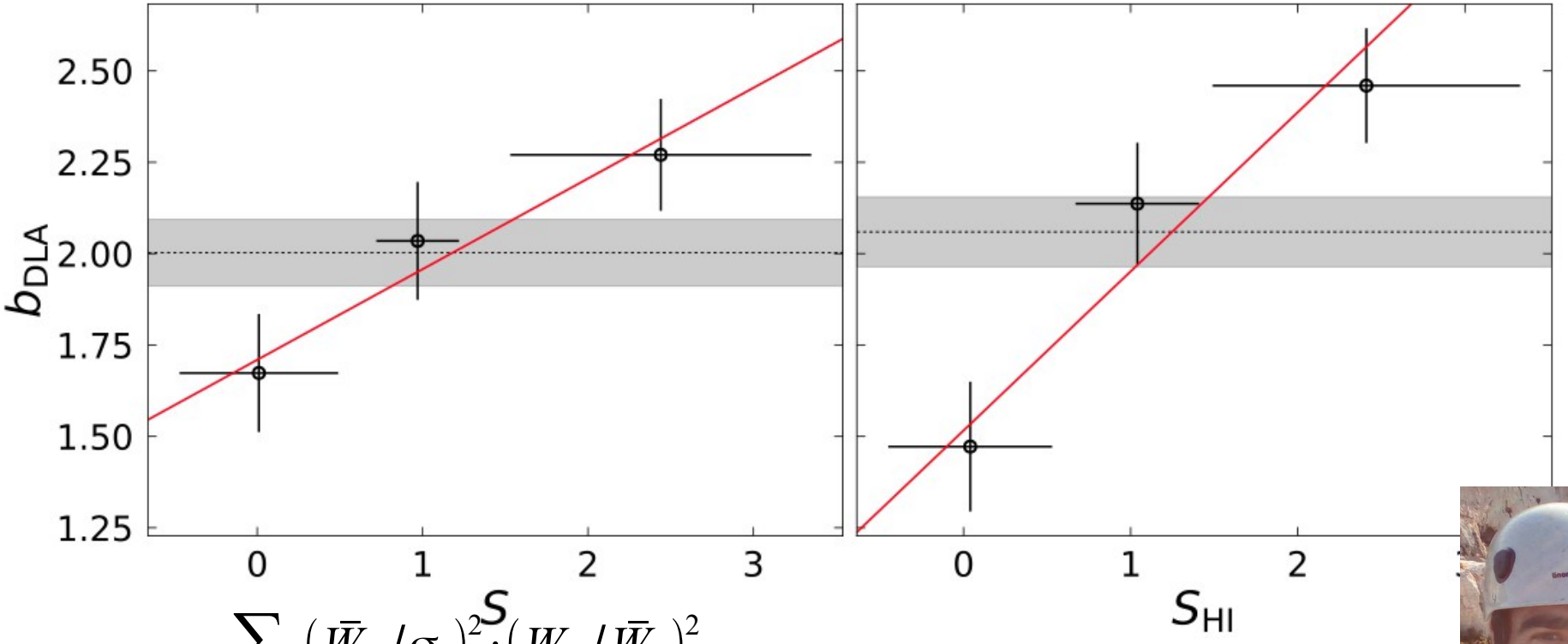
- Quasars
- Lyman Alpha Forest
- DLAs



Different kinds of DLAs **classified** by Metal Strength!

Lyα Cross-correlation and bias dependence on metal strength

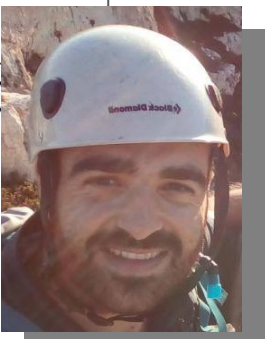
First observed evolution of the bias with a characteristic of the DLAs!



$$S = \frac{\sum_i (\bar{W}_i/\sigma_i)^2 \cdot (W_i/\bar{W}_i)^2}{\sum_i (\bar{W}_i/\sigma_i)^2}$$

Perez-Rafols 2018b,

arXiv:1805.00943



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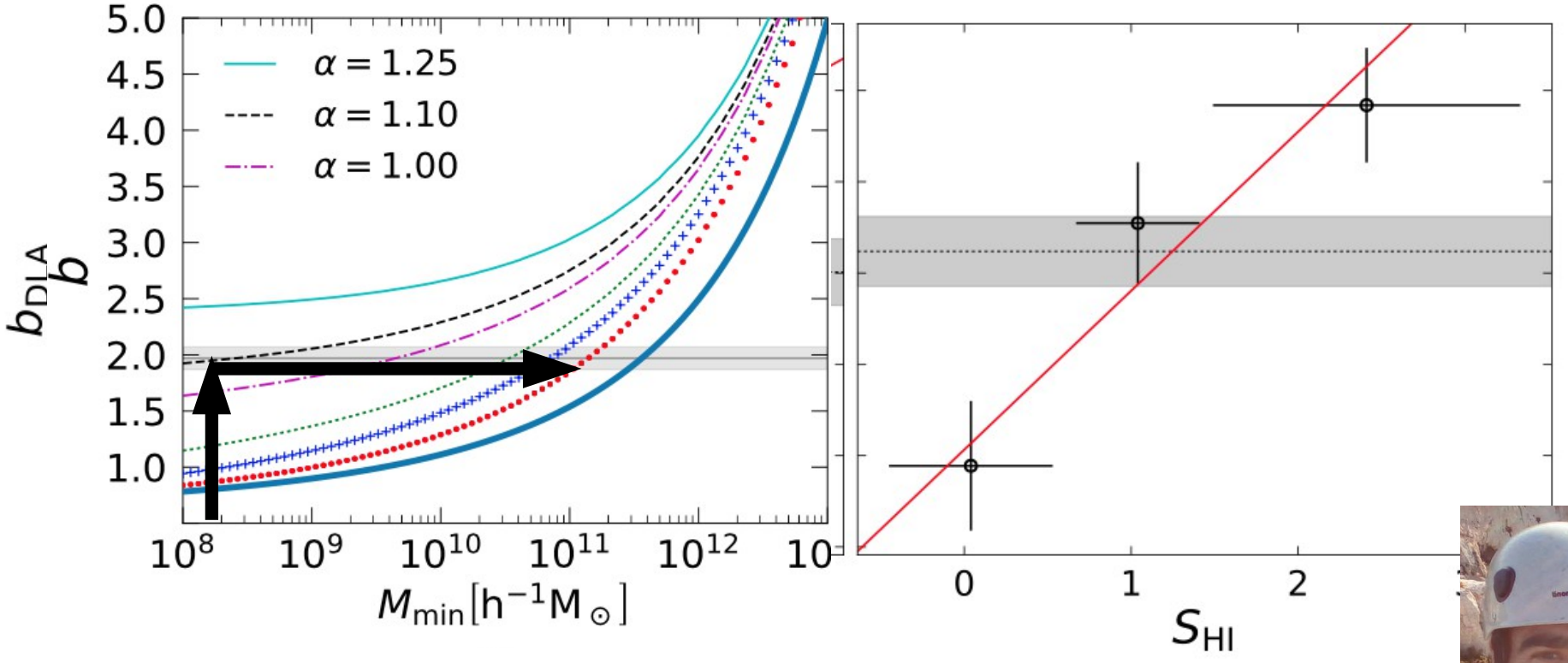
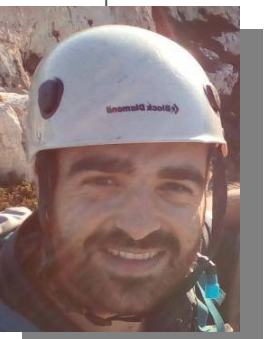




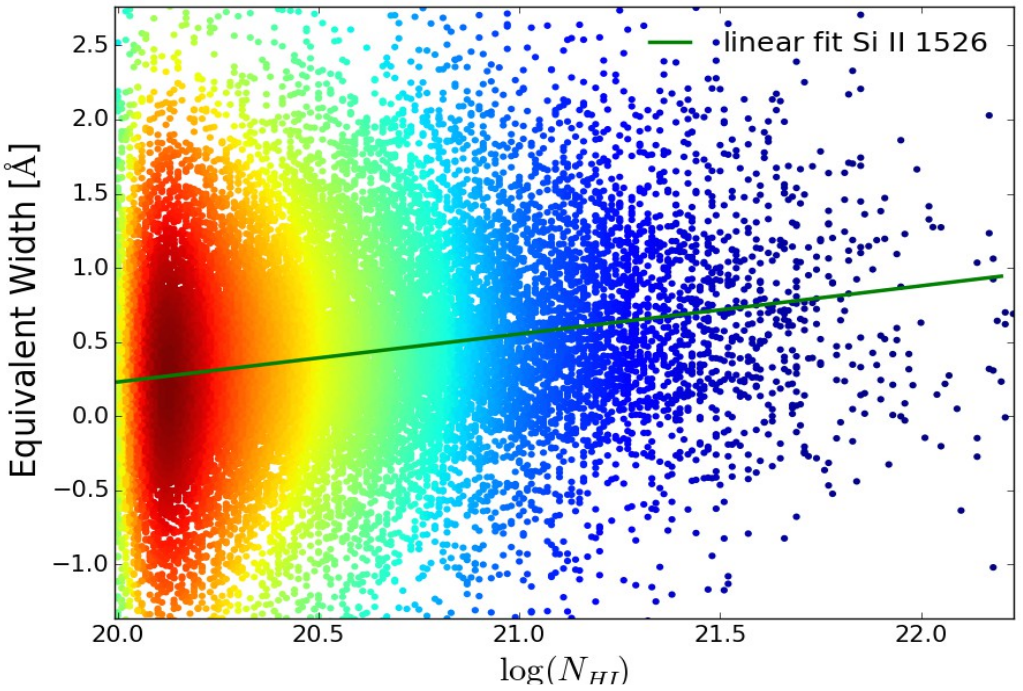
Perez-Rafols 2018b,

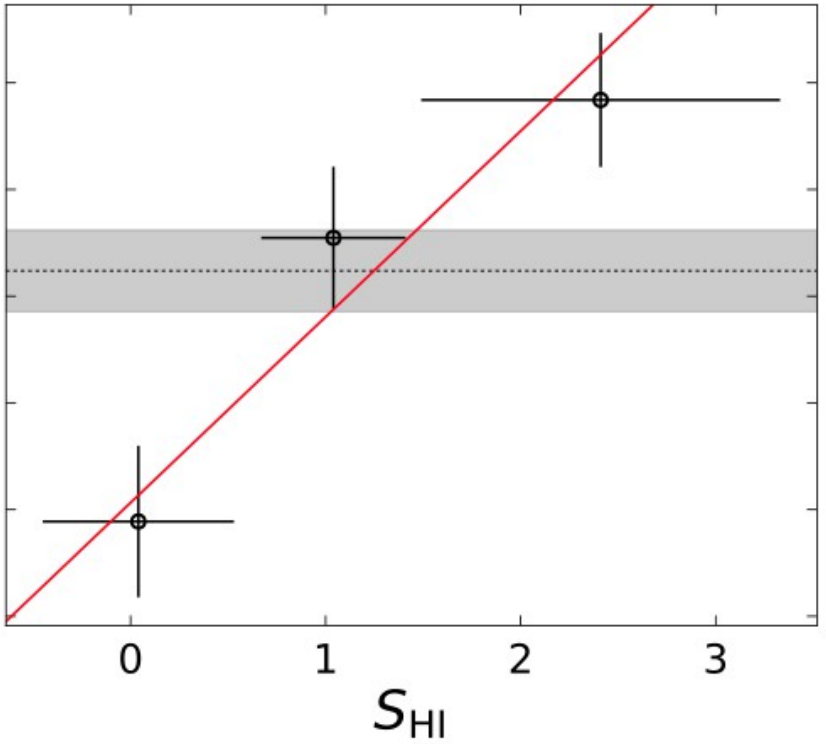
arXiv:1805.00943

Neutral Hydrogen column density correction

$$S_{HI} = \frac{\sum_k \left(\bar{W}_k(N_{HI})/\sigma_k\right)^2 \cdot \left(W_k/\bar{W}_k(N_{HI})\right)^2}{\sum_k \left(\bar{W}_k(N_{HI})/\sigma_k\right)^2}$$

$$\overline{W}_k(N_{\rm HI}) = a_k(\log(N_{\rm HI}) - 20) + b_k$$

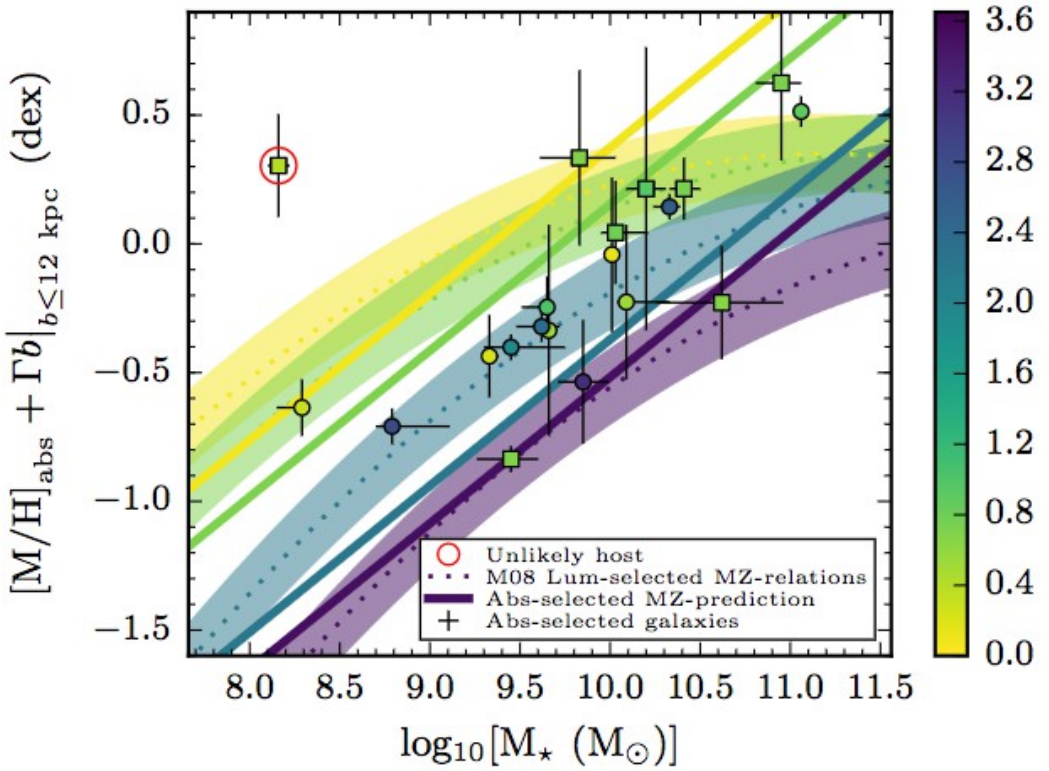




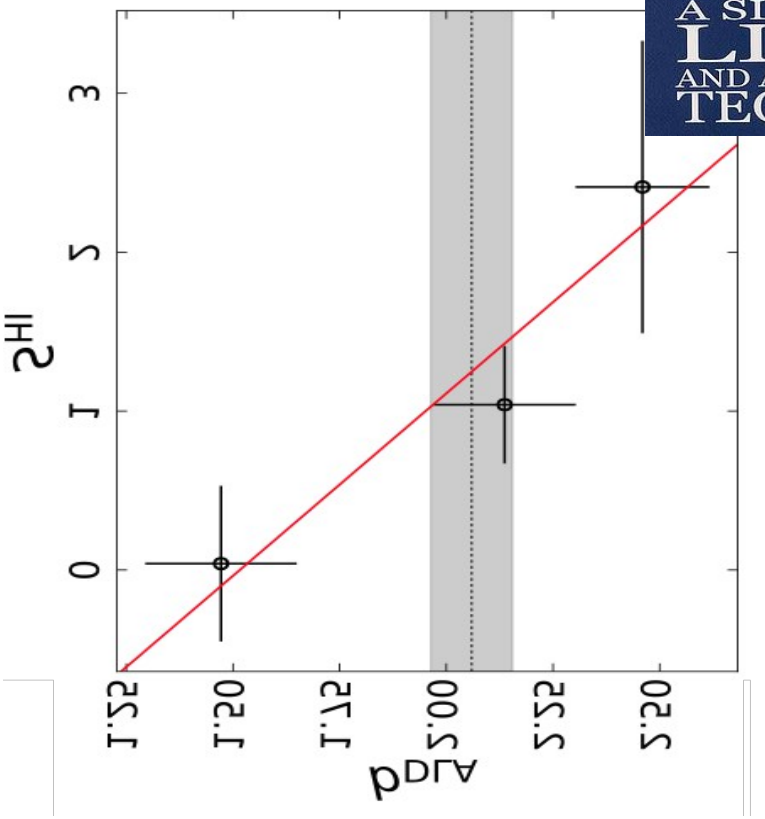
Perez-Rafols 2018b,

arXiv:1805.00943

Shamelessly using presented work,
Bias ~ Mass, Metal Strength ~ Metallicity

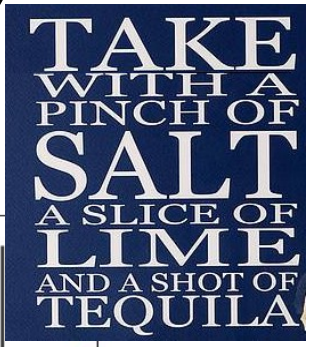


Rhodin et al 2018
arXiv:1807.01755



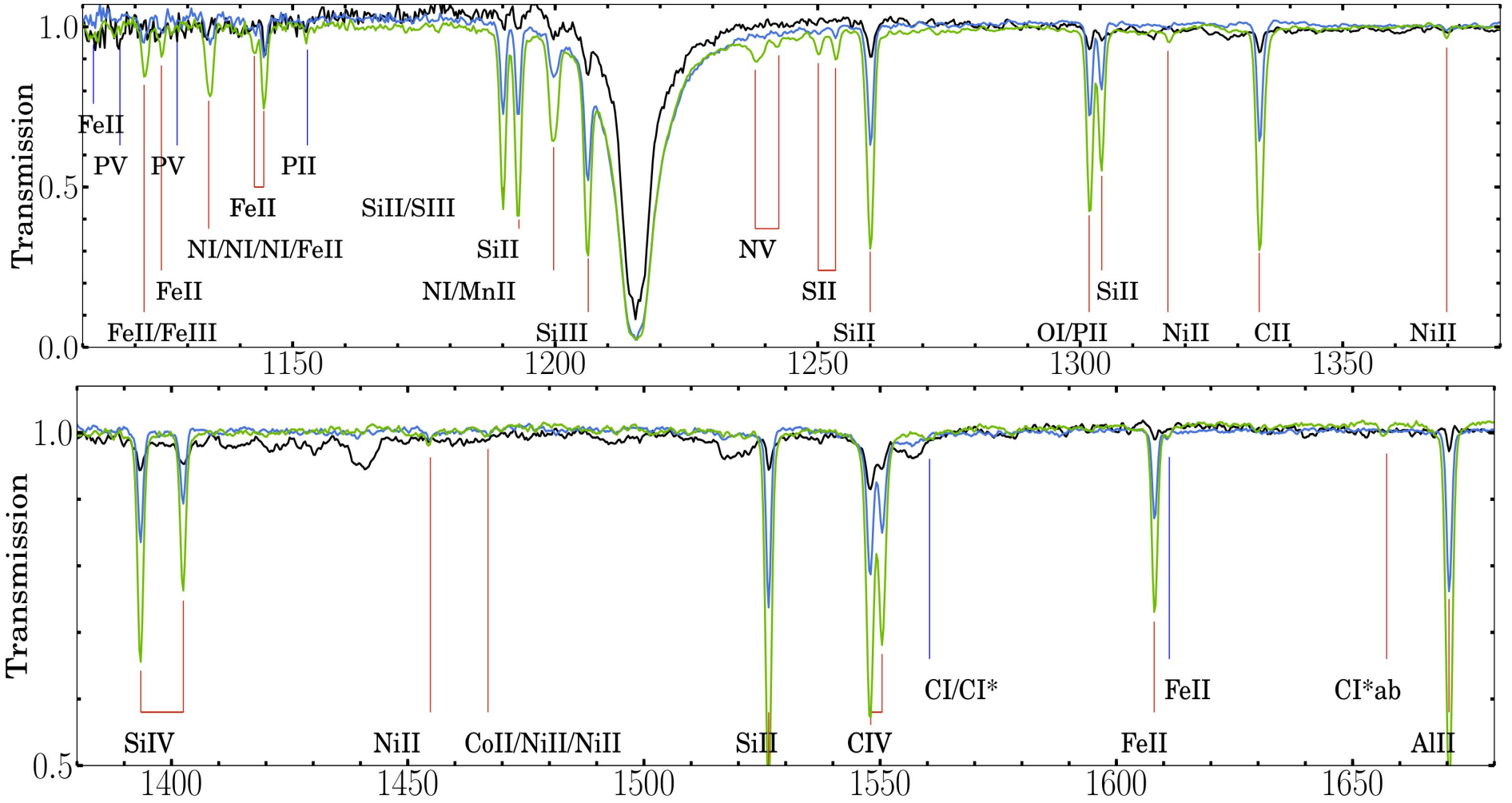
Perez-Rafols 2018b

arXiv:1805.00943



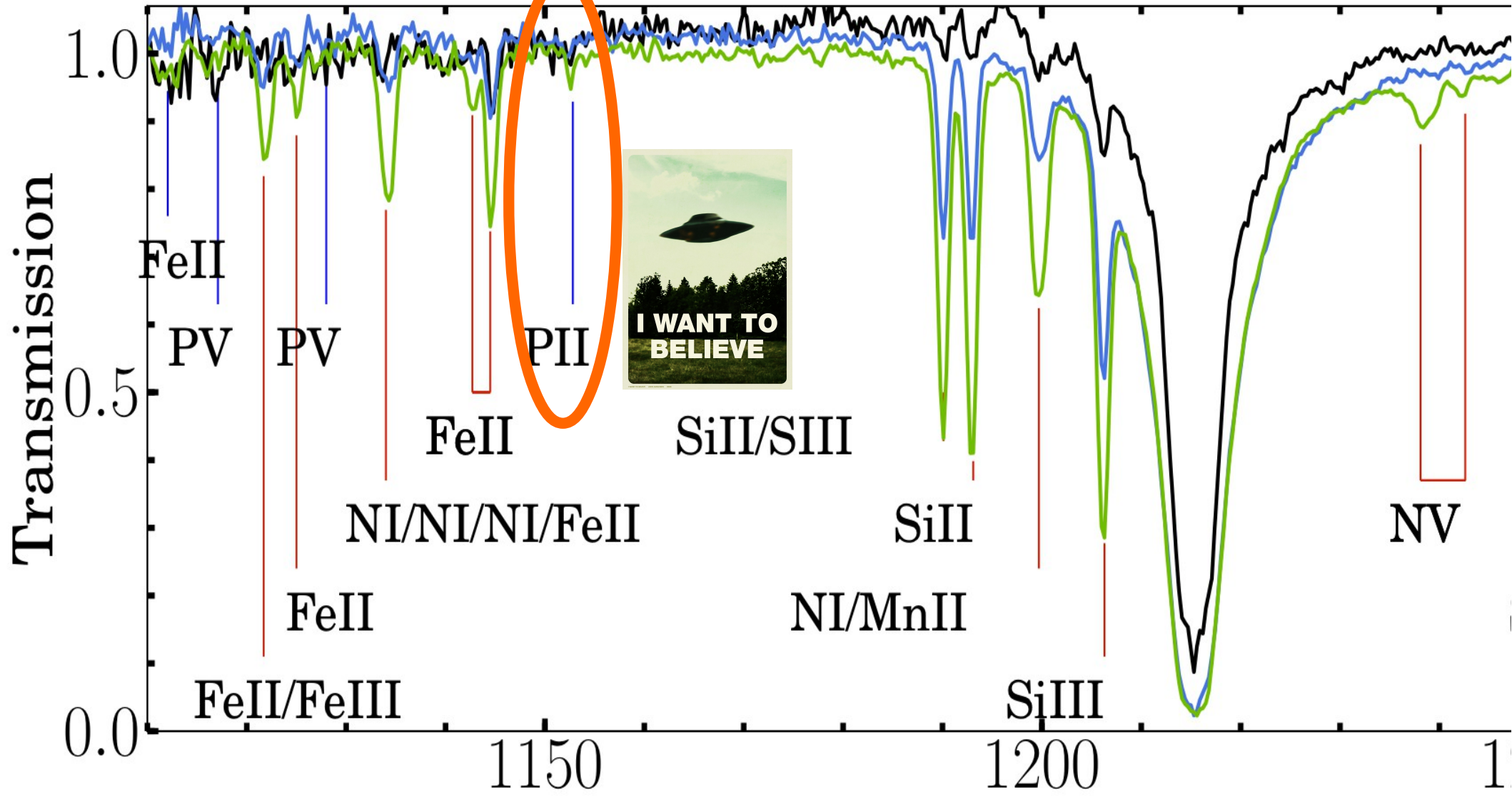
Stacked spectrum for 3 different Metal strength populations

With the collaboration of Mas-Ribas (work in preparation)



Stacked spectrum for 3 different Metal strength populations, new detections!

With the collaboration of Mas-Ribas (work in preparation)



DLAs: Conclusions

- Public catalogue of DLAs Equivalent widths & Metal Strength (google github Catalogue Metal Strength)
- First measurement of the bias as a function of the metal content of the DLAs
  - The evolution of b_{DLA} goes in the direction expected for metal dependency on halo mass
  - This is the first time that a bias has been measured as a property of the DLAs
- Population studies of stacked spectra depending on metal strength, many interesting studies!